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EFFECT OF MAGNET ERRORS ON SLOW EXTRACTION

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Summary

:alculate analytically the expected tune shifts ystematic sextupole and decapole errors in the oles of reference design A at an energy of The momentum-dependent tune shift due to sex- errors is $d\nu_x = -0.0557$ for $\Delta p/p = \pm 2 \times 10^{-5}$. om sextupole component in the SSC dipoles Δb_2 s less than 5×10^{-4}.

Introduction

tipole errors in the SSC magnets define the erture" for the fixed-target option. During extraction the amplitude growth of the reso- :illations is generated by nonlinear fields. sextupoles are utilized for 1/3-integer reso- raction. The field distortions present in the les and quadrupoles can perturb or suppress the growth of the oscillations.

systematic errors generate amplitude- and -dependent tune shifts; during the extraction these effects can cause (1) a reduction in step extraction efficiency, (2) curving of the ix, (3) possibly retrapping, and (4) emittance Random errors due to errors in coil placement example, interfere with the extraction harmon- ewise, random horizontal fields near the coils ng magnets can increase the vertical emittance he extraction process.

this short note we estimate analytically the fts caused by the multipoles in the SSC dipoles ence design A. We restrict the analysis to the systematic sextupole and decapole errors and s sextupole errors. The machine energy is tak-) TeV. Then from pp. 184-187 of the reference tudy[1] (RDS) we use for the systematic errors 10^{-4} cm^{-2}, $b_4 = 0.32 \times 10^{-4}$ cm^{-4}, and the ran- upole $\Delta b_2 = 1.6 \times 10^{-4}$ cm^{-2}.

Tune Shifts Due to Systematic Errors

tune shifts due to systematic errors were also d analytically for the SPS.[2] Approximate for- re developed that include only averaged quanti- e expressions require no tracking or integra- round the machine. Four formulas for the tune an be written

$$= -\frac{5\nu}{12R^2}\frac{\langle\beta^{5/2}\rangle^2}{\beta_{max}}\left(\frac{a}{A^2}\right)^2\left(b_2A^2\right)^2 \quad , \qquad (1)$$

$$= -\frac{\nu}{A^2\gamma_t^2}\frac{\langle\beta^{5/2}\rangle}{\langle\beta^{1/2}\rangle} b_2A^2\frac{\Delta p}{p} \quad , \qquad (2)$$

$$= -\frac{2\nu}{R}\frac{\langle\beta^{7/2}\rangle}{\langle\beta^{1/2}\rangle^3}\left(\frac{R}{\gamma_t^2}\frac{\Delta p}{p}\right)^3\frac{b_4A^4}{A^4} \quad , \qquad (3)$$

$$\Delta\nu_4 = -\frac{3\nu}{2\beta_{max}\gamma_t^2}\frac{\langle\beta^{7/2}\rangle}{\langle\beta^{1/2}\rangle}\frac{\Delta p}{p}\left(\frac{a}{A^2}\right)^2 b_4A^4 \quad . \qquad (4)$$

In Eqs. (1)-(4) ν is the horizontal betatron tune (we assume $\nu = 97^{1/3}$), R is the machine radius (R = 14.324 km), a is the amplitude of the betatron oscillation of the particle measured at $\beta = \beta_{max}$, A is the aperture of the magnet, and $\Delta p/p$ is the relative deviation of the particle momentum from the nominal value. The averaging of the listed powers of beta was accomplished by averaging over the standard 200-m FODO cells.[1] We obtain $\langle\beta^{1/2}\rangle = 11.8$ m$^{1/2}$, $\langle\beta^{5/2}\rangle = 378 \times 10^3$ m$^{5/2}$, and $\langle\beta^{7/2}\rangle = 85.3 \times 10^6$ m$^{7/2}$.

Equation (1) is the amplitude-dependent tune shift due to sextupole errors and Eq. (2) is the nonlinear momentum-dependent tune shift. Equations (3) and (4) represent the tune shifts due to decapole errors--in the former case the shift is just due to $\Delta p/p$ effects; for the latter the tune shift arises from combined $\Delta p/p$ and amplitude dependence. The nonlinear equations used to obtain Eqs. (1)-(4) are solved in Landau and Lifshitz.[3]

Equations (1)-(4) were evaluated assuming the SSC aperture A = 10 mm, $\gamma_t = 88.35$, $\beta_{max} = 332$ m, and a = 5 mm. We obtain $\Delta\nu_1 = -0.001$, $\Delta\nu_2 = -0.0557$, $\Delta\nu_3 = -2 \times 10^{-7}$, and $\Delta\nu_4 = -0.0011$. For resonant extraction the $\Delta\nu_2$ term will be fatal if the b_2 multipole is not corrected by at least a factor of ~20. The stopband width around $\nu = 97^{1/3}$ should be near ±0.005.

Effects Due to Random Errors

Random sextupole fields in the bending magnets can give rise to a sextupole component with, for example, a 292nd harmonic that interferes with the 292nd harmonic generated intentionally for extraction at $\nu = 97^{1/3}$. The harmonic is given by[4]

$$S_{rds} = -\frac{1}{\beta_{sep}^{1/2}\,B\rho}\oint\frac{B_0}{A^2}\frac{\Delta B}{B}\beta^{3/2}\cos(292\phi)\,ds \quad , \qquad (5)$$

where B_0 is the dipole field (6.5 T), $\Delta B/B$ is the fractional error field at the aperture A, $\phi = \int ds/(\nu\beta)$, and β_{sep} is beta at the slow-extraction septum. For random errors we write

$$S_{rds} = -\frac{B_0}{\beta_{sep}^{1/2}\,B\rho\,A^2}\left\{\sum\left[\ell_d\beta^{3/2}\cos(292\phi)\right]^2\right\}^{1/2}\left\langle\frac{\Delta B}{B}\right\rangle \quad .(6)$$

To simplify matters we assume $\beta^{3/2}$ is constant over the 3870 SSC dipoles, A = 10 mm, ℓ_d ~ 16.6 m, and β_{sep} = 1500 m in the center of a utility straight section. We arbitrarily choose S_{rd_m} to amount to no more than 25% of the harmonic generated by the extraction sextupoles, which we have calculated to be $S_h = 133.3\ m^{-1}$. This condition then requires [from Eq. (6)] that $\langle \Delta B/B \rangle \leq 5.0 \times 10^{-4}$. The SSC dipoles do satisfy this requirement.

Conclusions

Based on the above analysis it appears that slow resonant extraction can proceed with a "good field aperture" of 1-cm radius in the SSC, providing that the systematic sextupoles for the dipoles (b_2 as listed on p. 184 in Ref. 1) can be reduced by at least a factor of 20.

References

1. SSC Reference Design Study For U.S. Department of Energy, May 8, 1984.

2. Y. Baconnier, K. H. Kissler, and B. de Raad, "Effect of Field Distortions in the 300 GeV Main Ring Bending Magnets," CERN report 300-BT/71-2 (July 1971).

3. L. D. Landau and E. M. Lifshitz, in Mechanics (Pergamon Press, Oxford, 1976).

4. D. A. Edwards, "Comparison of Half Integer and Third Integer Extraction for The Energy Doubler," Fermilab report TM-842 (1978).